21st Conference of the Canadian Nuclear Society
Toronto, Ontario, Canada / June 11-14, 2000

Application of Operating Experience in Environmental Qualification Program

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1. Introduction

Environmental qualification (EQ) of equipment related to nuclear safety has been carried out in the nuclear community since the 70's. It started with electrical equipment and then expanded to include mechanical equipment. During this evolutionary process, the methods used for EQ have gone through a long period of refinement and clarification.

Prior to 1971, qualification for equipment in licensed nuclear power plants was based on the use of electrical components of commonly accepted high industrial quality without the benefit of specific environmental qualification standards.

Between 1971 and 1974, most plants used the criteria of IEEE Standard 323-1971 as the basis for demonstrating qualification. Also during this period related "daughter" standards, mainly by IEEE, became available which addressed qualification for specific equipment items.

After July 1974, plants were required to meet the more comprehensive guidelines specified in IEEE Standard 323-1974 and the related "daughter" standards. IEEE Standard 323-1974 later evolved into IEEE Standard 323-1983.[1]

For nuclear power plants built in Ontario during the 70's, i.e. Pickering B and Bruce B, has included the environmental qualification requirements in their respective nuclear safety design guides. It is now recognized that they are not up to the current EQ standards. Darlington, constructed during the 80's, implemented the environmental qualification program in its project. An Environmental Qualification (EQ) Program is now under way in Ontario Power Generation (OPG) to formally implement the Environmental Qualification for Bruce B, Pickering B, and Pickering A and to preserve the Qualification for Darlington G.S.

This paper makes a thorough a review of the standard methods used in the past by utilities for environmental qualification. These methods include type testing, analysis, and operating experience. Both type testing and analysis have been clearly defined in standards listed in References [2] to [6] and widely used by nuclear utilities in the past two decades. On the other hand, the use of operating experience has had limited application.

In order to better position the use of operating experiences in nuclear power plants (NPP); this paper takes a rigorous review of the process involved in the EQ program and to formulate a set of equations to describe the EQ process. These equations identify the role of the methods used in achieving the EQ status. Consequently, these equations establish a baseline for the use of operating experiences in supplementing the qualification established by testing and analysis.

This paper also formally defines the scope of using operating experience in EQ, and proposes a guide to compile, process and interpret data gathered such that they will be readily available to support the environmental qualification program.

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[1] The brief review was quoted from Reference [1]

2. Environmental Qualification Program

The purpose of Environmental Qualification (EQ) Program is to provide auditable assurance that essential safety-related equipment and systems, required to mitigate the consequences of a design basis accident (DBA), will perform its intended function when exposed to harsh environmental conditions resulting from that accident, and that this capability will be maintained over the life of the stations.

The EQ Program also includes the controls necessary to maintain the qualified status of the equipment over the life of the plants.

The scope of safety related equipment and systems to be considered includes all credited functions performed by special safety systems, safety related systems, support systems, and any other components whose failure due to harsh post-accident environment can impair the capability of the required safety equipment and systems to function as required. Electrical and control components as well as mechanical components whose performance may be adversely affected by the post-accident environment will also be considered.

The design basis accident conditions addressed by the “Environmental Qualification” program are a subset of the service conditions which are required to be addressed as part of “Equipment Qualification”.

The EQ Program considers both normal and DBA environmental parameters[2] (or stressors). The normal operating environmental parameters that must be considered by the EQ Program are those which may result in “age related degradation” in the performance capabilities of equipment and components or result in environmentally induced failures under DBA conditions. As a minimum, this includes “*thermal, radiation,* and *cyclic ageing*”. Other parameters such as “*humidity, voltage* and *vibration*” are also considered. The post-accident environmental parameters which must be addressed within the scope of the EQ Program are those which are sufficiently widespread in their effect to have the potential to result in common cause failures which can adversely affect the performance of materials that are age sensitive. This includes the following environmental parameters, *Temperature, Pressure*, *Humidity, Radiation, Chemical Effects* and *Submergence.*

Service conditions associated with seismic qualification, severe weather (tornado, freezing, external floods), dynamic effects, electromagnetic interference (EMI) and radio frequency interference (RFI) and fire protection are examples of design issues related to “Equipment Qualification” that are *outside* of the scope of the EQ program.

A simple analogy may be drawn between the EQ program of an operating nuclear power plant (NPP) and the “*Health Care”* program for people. Common health care program deals with ageing related degradations caused by normal and abnormal living conditions. The health care ensures that the vital systems (organs) retain their functional capabilities during the ageing process and be able to stand serious sickness (i.e. heart attack) towards the end of the expected life span. For a structured health care program it should include:

- Identify the daily stressors that cause the ageing related degradation. (Diagnosis)
- Develop methods to assess the ageing related degradation effects. (Procedures)
- Set up rules to mitigate conditions that promote the degradation process. (Prescriptions)
- Establish a “Qualified Life Expectancy”.

Once a qualified Life has been established, it is prudent (and wise) to follow the doctor’s “prescriptions - rules”, make on-going visit to the “methods” for possible improvement in slowing down the ageing process, continuously review and re-examine the sources of “stressors” to preserve the qualified status and finally, live a healthy life to meet the expectancy.

[2] “Environmental Parameter” is used in OPG EQ Program, whereas “Stressor” is used in the EPRI Equipment Qualification Manual [7].

The same principles of this "Health Care Program", when applied to a Nuclear Power Plant, is the Environmental Qualification Program.

3. Qualified Life

The centre stage of the Environmental Qualification Program is the determination of the "qualified life" for equipment and components of the essential safety systems, given the service conditions established in the nuclear power plant, including the harsh environmental condition during a DBA.

Qualified Life, as defined in IEEE 323-1983 [3], is

> "*The period of time, prior to the start of a design basis event, for which equipment was demonstrated to meet the design requirements for the specified service conditions*."[3]
>
> A note under the definition states: "*At the end of the qualified life, the equipment shall be capable of performing the safety function(s) required for the postulated design basis and post-design basis events*."

The measurement of the equipment being *"capable of performing the safety function(s) required for the postulated design basis and post-design basis events"* is called the *"Functional Capability".*

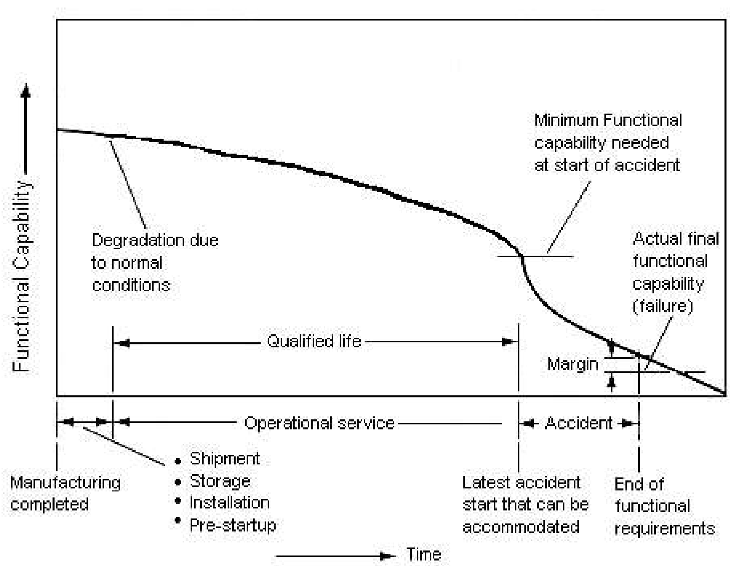

Fig. 1 Qualified Life for Typical Equipment

Fig. 1 shows the qualified life of typical equipment. The functional capability of the equipment declines by the ageing degradation effect of normal service condition. The functional capability would be further reduced by a postulated design basis accident until it reaches to the end of functional requirement (with a margin).

Functional Capability consists of two parts:

(1) The functional requirements of the equipment and systems, which is determined by the system requirement in respect to its safety function in the nuclear power plant.

[3] A more explicit definition describes qualified Life as the "Period for which an SSC (Structure, System, Component) has been demonstrated, through testing, analysis, or experience, to be capable of functioning within *acceptance criteria* during specified operating conditions while retaining the ability to perform its safety functions in design basis accident or earthquake." (Grant, W.S. and E.J. Miller, Nuclear Power Plant Common Ageing Terminology, EPRI Final Report TR-100844, December 1992.)

(2) The capability of the equipment, which is in term, determined by the components and material make-up the equipment.

Certain components and material are affected by ageing related stressors. For any equipment, its Functional Capability varies with the role it takes in the NPP. The same equipment may have different Functional Capability requirements. For example: a pump required to circulate process fluid in a DBA is different from the same type of pump required to maintain only the pressure boundary.

Based on the above definition, the qualified life for any equipment can be shown in the following equation (1):

$$\text{Qualified Life}_{(\text{Equipment/service conditions})} = \max \left\{ t: \begin{array}{l}\text{Equipment capable of meeting the design requirements prior}\\ \text{to the start of a design basis event, and at the end of the}\\ \text{qualified life, the equipment is capable of performing the safety}\\ \text{function(s) required for the postulated design basis and post-}\\ \text{design basis events with a margin.}\end{array} \right\} \quad (1)$$

This equation can also be written in the following form:

$$\text{Qualified Life}_{(\text{Equipment/service conditions})} = \max \left\{ t: \text{ Functional Capability} \geq \text{Acceptance Criteria} + \text{Margin} \right\} \quad (2)$$

It should be noted that the determination of acceptance criteria is not a simple task. It may require extensive *system analysis, supplementary tests* or *feedback from operating experience.* Therefore equation (2) (and hence equation(1)) may involve all three methods to refine its parameters.

Since equipment in most cases is an assembly of components, the equipment qualified life can be determined from the qualified life of components as shown in the following equation (3). For simplicity, the service condition is assumed given.

$$\text{Qualified Life}_{(\text{Equipment})} = f\left(\text{Qualified Life}_{(\text{component})}, \text{ Inter-component Degradation Effects}\right) \quad (3)$$

Where the "Inter-component Degradation Effects" is the degradation that can not be traced to any particular identified component in the equipment. It may be introduced by the physical configuration of the equipment (such as relative thermal expansion between components) or caused by some unidentified material in the construction of the equipment (such as unlisted lubricants). One indication of such effect is when the equipment life is less than the qualified life of all components making up the equipment. In the qualification process, the type testing may identify certain inter-component degradation effect, but more commonly it will be identified by reports from the operating experience.

If the Inter-component Degradation Effects is proven not relevant to the qualified life for the equipment, then the relationship between the equipment qualified life and the component qualified life can be determined by the following equation:

$$\text{Qualified Life}_{(\text{Equipment})} = \min \left\{ \text{Qualified Life}_{(\text{component } 1)}, \ldots, \text{Qualified Life}_{(\text{component } n)} \right\} \quad (4)$$

At the component level, the material characteristics in response to the environmental stressors will determine the equipment's life in the service condition. The qualified life for "any one component" in an equipment can be shown as

$$\text{Qualified Life}_{(\text{Component/Service Condition})} = f \text{ (Effect of Stressors, Synergistic Effects)} \quad (5)$$

Where the “Service Condition” includes both the normal operating condition and the design basis accident condition. Consequently, the “Effect of Stressors” also takes account of both conditions.

The “Synergistic Effect” is the combined effect of more than one ageing related stressors to the component material. The most well known effect is the dose-rate effect and effect resulting from the application of different sequences of accelerated ageing by radiation and temperature.

For known stressors, their synergistic effect can be established by type testing. However, for effects caused by unknown stressors, the only possible source would be from the operating experience.

If the synergistic is verified not an issue in the ageing related degradation, then the qualified life of a component can be written as:

$$\text{Qualified Life}_{(\text{Component/Service Condition})} = \min \left\{ \text{Life}_{(\text{component /stressor 1})}, \ldots, \text{Life}_{(\text{component/stressor n})} \right\} \quad (6)$$

In general, the life of a component for one identified ageing related stressor can be represented by the following equation:

$$\text{Life}_{(\text{Component/stressor})} = f \text{ (Characteristics of Material in response to Stressor, Service Conditions)} \quad (7)$$

The above equation is the expression of a generic ageing model. At the present time, there are relatively few ageing degradation models commonly used: the Arrhenius model addressing thermal ageing and the equal dose/equal damage model addressing radiation ageing. There are less developed models for other types of stressors such as humidity, voltage, vibration and operational stressors listed in the EPRI Equipment Qualification Manual. [7]

In summary, the equations (1) to (7) above describes the hierarchy of the EQ process. This can be considered as the mathematical foundation of a generic EQ Program.

In the EQ Program, the process to determine the qualified life of equipment (given the Service Conditions including the period prior to the start of a DBA and the harsh environment during a DBA) is called EQA – the “Environmental Qualification Assessment”, which includes:

(1) Collection of referenced design documents, identify the equipment configuration, material used in the components and parts, etc.
(2) Provides the auditable proof that Equipment is environmentally *qualified.*

The “auditable proof that Equipment is environmentally qualified” will be established by the qualification methods to be described in the following section.

4. Qualification Methods

Qualification methods have been specified in several documents including, IEEE Std 323-1974, IEEE Std 323-1983, and CSA N290.13.

The method for establishing qualified life for equipment and component may be achieved by the use of any of the following methods: “Type Testing”, “Analysis”, “Operating Experience” and/or the combination of the three methods. These three methods are not mutually exclusive and are not standing on the same basis. Type testing in some cases requires analysis to prepare the test specification. However, operating experience can supplement the results of both type testing and analysis.

Qualification by Type Tests

The objective of qualification testing is to demonstrate that the equipment and safety systems can perform their safety related functions, within specified performance limits, under simulated Design Basis Accident (DBA) conditions after being aged to an end of life condition.

The test method of qualification involves testing an identical or similar item of equipment under conditions which simulate or bound the required service conditions with a supporting analysis to show that the equipment to be qualified is capable of performing its required function. The test specification should include "*thermal, radiation*, and *cyclic ageing*", as well as "*humidity*, *voltage* and *vibration*". These simulate normal service conditions along with the following environmental parameters: *Temperature, Pressure*, *Humidity, Radiation, Chemical Effects* and *Submergence* to simulate a DBA environment.[4]

Requirements for type test are governed by Equation (7) for individual component, Equation (5) for effect of various stressors and Equation (3) for establishing equipment qualified life (Section 3).

Type testing is the preferred qualification method to demonstrate that the equipment performance meets or exceeds the required safety function under the specified service conditions. Type testing can achieve this goal with relatively high confidence.

Type tests also include un-aged or incrementally aged specimens of equipment, which has known failure modes, or mechanisms which vary or change over time. Type tests for EQ are executed in a specific order. The sequence used must be justified as being appropriate for the equipment being environmentally qualified. The same test specimen(s) should be exposed to the entire test sequence. Justification must be provided when test specimen(s) are substituted, replaced or refurbished during the test sequence or when separate effects testing is used to establish qualification. Baseline inspection and functional performance tests must be performed prior to the start of testing. This baseline inspection and functional tests should not be directed to select a specific unit for type testing. Inspections and functional tests shall be used after each major step in the test sequence and compared to the baseline values. The test sequence used should simulate an end of life condition for the equipment prior to exposure to the simulated DBA environmental conditions. Any changes, modifications or replacement of the test specimen(s) during the test sequence must be reviewed to determine the impact on qualification.

Type test *may* be able to detect the Inter-component effect described in Equation (3) and the Synergistic effect described in Equation (5). Due to the limitation of the test facility, there are possibilities that those effects may be not be identified by the type test.

Qualification by Analysis

Qualification by analysis requires the construction of a "*valid mathematical model*" of the equipment to be qualified in response to environmental stressors. The performance characteristics (such as the qualified life) of the equipment are dependent variables and the environmental influences (such as stressors, service conditions) are the independent variables. The final measure of the performance characteristics of the equipment is the *qualified life* of the equipment.

Equation (1) to (7), describe the environmental qualification process can be used as a guide for analysis. In particular, Equation (7) describes the functional requirements for the ageing model. Ideally, Equation (7) should be applicable to each stressor identified in the EQ Program, that is:

[4] Type tests to establish EQ may be performed in accordance with applicable industry standards, such as IEEE-323 – "Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations." [3]

thermal, radiation and cyclic ageing, as well as humidity, voltage and vibration. Currently, only thermal ageing and radiation ageing have valid model with limited applicability. At this time, there are either no acceptable models or no universal models for other types of stressors. [7]

Furthermore, the validity of the mathematical model must be justified by test data, *operating experience*, vendor data, and established engineering principles that support the analytical assumptions and conclusions.

The validity of the model for thermal ageing effect has been reasonably developed. The use of the Arrhenius methodology for thermal ageing calculations is shown in an EPRI report.[5] When applied to qualification, the analysis must include the *rationale* for extrapolation and engineering judgement. An adequate safety factor should be used to ensure that sufficient conservatism exists to account for uncertainties such as, but not limited to, manufacturing variations, synergistic effects, and differences in material formulations and extrapolation of data.

Qualification by analysis should consist of a quantitative analysis of the mathematical model of the equipment. This logically proves that the required performance characteristics (i.e. functional capability) of the equipment meets or exceeds the equipment design specifications when the equipment is subjected to a harsh environment post-accident for the required mission time.

Qualification by Operating Experience

Equipment that has historically operated successfully can be considered qualified for equal or less severe service conditions. *Operating experience can also provide information on* ***limits of extrapolation****,* ***ageing characteristics*****,** ***failure modes****, and* ***failure rates***. The validity of operating experience as a means of qualification shall be determined from the type and amount of documentation supporting the service conditions and equipment performance, maintenance, and similarity between the equipment to be qualified and that for which operating experience exists.

Due to the lack of supporting documentation, the use of operating experience for complete EQ has been limited. However, the use of operating experience has been embedded in the current EQ Assessment process. Environmental Qualification issues such the identification of stressors, the inter-component effects as described in Equation (3) and the synergistic effects in Equation (5) are typical examples where operating experience can enhance the EQ program and preserve the EQ status.

Combined Qualification

Equipment may be qualified by test, analysis, operating experience analysis or any combination of these methods. Partial type testing may be augmented by tests of components where size, applications, time, or other test limitations preclude the use of a full type test. Examples of combined qualification include partial type tests with extrapolation or analysis, operating experience with extrapolation or analysis, and type tests supplemented with tests of components and analysis.

Among these methods, type testing and analysis are the most commonly used ones in the nuclear industry for the establishment of equipment qualification. Operating experience in the past was a method of limited use as a sole means of qualification but, of great use for verifying tests. The results may provide an insight into the change in behaviour of materials and equipment with time under actual service and maintenance conditions. However, as more testing reports become readily available and more analyses are performed on equipment commonly used in the nuclear utility community, the use of operating experience to enhance the qualification status will become more important for nuclear power plants.

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[5] EPRI-NP-1558, A review of Equipment Ageing Theory and Technology Research Project 890-1, September 1980.

5. On-going Qualification

The Environmental Qualification Program is an on-going task to ensure the equipment and components which are essential to provide a safety function consistent with the assumptions and requirements documented in the current safety analysis will perform its function in the event of DBA.

Fig. 2 shows the qualified life reduced by degradation due to abnormal condition.

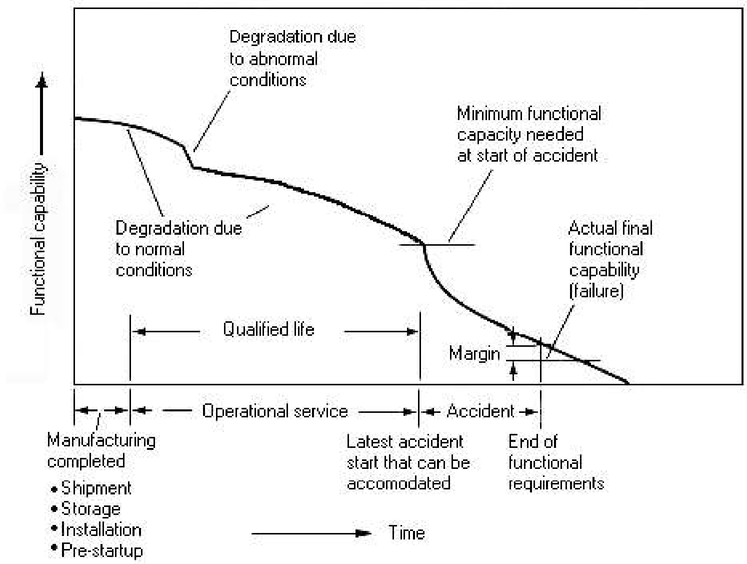

Fig. 2 Reduction of Qualified Life Caused by Abnormal Condition

Based on the seven equations proposed in this paper, the EQ Program will achieve and maintain the plant life in two stages:

1. To maximise of the qualified life of “components” of equipment in the essential safety systems by:
   - Identify and manage the ageing degradation stressors
   - Mitigate the service environmental conditions, both in operation and during a DBA
   - Identify and manage the synergistic effects
2. Maintain the qualified life of “equipment” in the essential safety systems by:
   - Inspection
   - Surveillance
   - Condition Monitoring
   - Maintenance
   - Refurbish/replacement

The previously described qualification methods may yield a qualified life of equipment that is less than the anticipated installed life of the component, or the qualified life may be reduced by ageing degradation caused by abnormal conditions. When this occurs, an on-going qualification program may be implemented. Fig. 3 shows the maintenance or refurbishment resulted in the extension of qualified life.

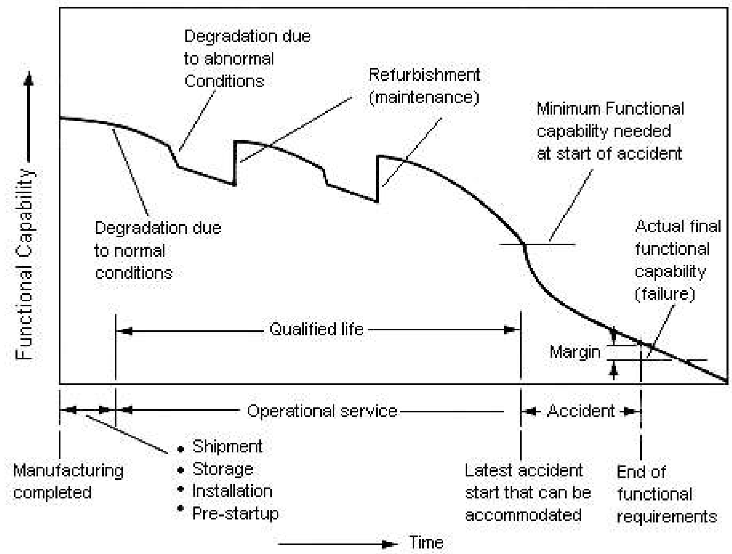

Fig. 3 Restoration of Qualified Life by Maintenance

6. Application of Operating Experience

As stated previously in this paper, the use of operating experience in EQ Program is limited due to the lack of supporting documentation, therefore, it is necessary to pursue this subject from the basic definition of operating experience.

Standard Definition:

> "Operating Experience" is the "*accumulation of verifiable service data for conditions equivalent to those for the equipment to be qualified or for which particular equipment is to be qualified*." (IEEE Standard Dictionary of Electrical and Electronics Terms)[6]

It appears in the above IEEE definition that it emphasises only the "data aspect" of experience. Implied in this definition includes the following activities:

1. The action to accumulate the data.
2. The action to verify the data for EQ applications.
3. The action to make use of the data for EQ applications.

The use of operating experience in the EQ Program has been described in the following EQ related standards:

> *Operating experience* can provide information on **limits of extrapolation**, **failure modes**, and **failure rates**. (IEEE 323-1974) [2]

> Operating experience can provide information on **limits of extrapolation**, **ageing characteristics**, **failure modes**, and **failure rates**. (IEEE 323-1983) [3]

> Operating experience can provide information on **limits of extrapolation, ageing characteristics, malfunction modes and rates, equipment performance,**

[6] This definition is adopted in the EPRI Equipment Qualification Manual. [7]

and maintenance requirements. (American Society of Mechanical Engineers, ASME QME-1-1994) [4]

Incidentally, the descriptions themselves are like the “operating experience” - they grow through the years with continuously improved understanding about what “experience” means to EQ.

In the past the application of operating experience in EQ is limited because there is the lack of data available for equipment that has been exposed to harsh environment such as main steam line break (MSLB) environments and/or high-radiation environments [6]. While MSLB events do occur, there is no sufficient data collected to permit determinations of applicable environmental conditions, affected equipment, installation configuration and demonstrated performance.[7]

The following statement from the EPRI Equipment Qualification Manual [7] can better describe the importance of operating experience to the EQ program:

> *“The prediction of ageing related degradation is complex and involves many uncertainties. A universal engineering model for predicting ageing as a function of time or use does not exist. Research continues to provide new information for improving the **state of the art** of ageing prediction. Generally the new information indicates that either more complex models must be developed or additional uncertainties must be considered. As a result, **judgement, experience, and operational feedback** are important elements of an effective ageing evaluation.”*

This statement addresses the following issues:

- There are many uncertainties involved in EQ.
- There is no eternity in EQ status in a dynamic nuclear power plant - there is a need for continuing effort to preserve the EQ status.
- **Judgement, experience, and operational feedback** are important elements of an effective ageing evaluation to supplement the EQ efforts and to preserve the EQ status.

OPG Nuclear (OPG-N) has an OPEX Program to identify and communicate lessons learned from plant events world-wide, so staff can take action to prevent similar events at OPG-N sites. The type of information include OPG-N internal Station Condition Reports (SCRs), the external WANO/INPO Significant Operating Experience Reports (SOERs) and Significant Event Reports (SERs)

The following chart illustrates a proposed feedback loop using the OPEX information for the EQ Program.

[7] Prior to the accident at the Three Mile Island unit 2 (TMI-2) plant in 1979, no historical events have involved both high radiation and steam, pressure, temperature conditions on equipment in nuclear plants in North America.

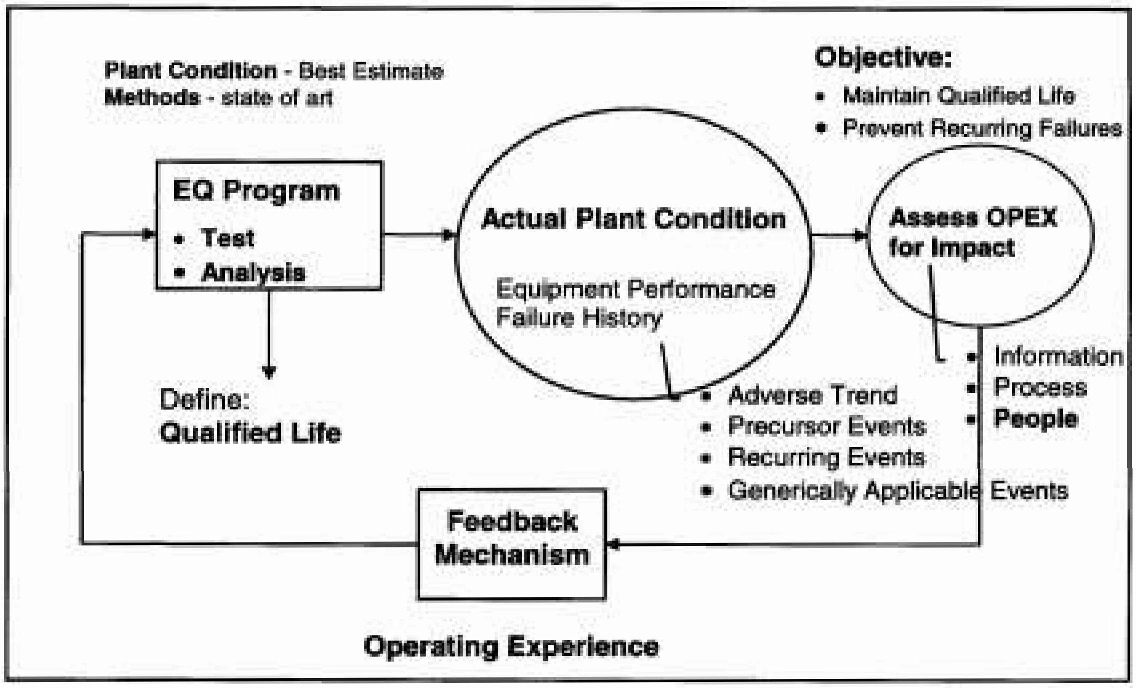

Fig. 4 Incorporating Operating Experience to EQ Program Preservation

The purpose of the feedback loop is for the use of operating experience to:

1. Maintain Qualified Life
2. Prevent Recurring Failures

Operating experience can provide information on limits of extrapolation, ageing characteristics, malfunction modes and rates, equipment performance, and maintenance requirements.

Definition: Operation Experience for Environmental Qualification

> "Operating Experience" for EQ Application is:
>
> "*Accumulation of verifiable service data for conditions equivalent to those for the equipment to be qualified or for which particular equipment is to be qualified*."
>
> In addition,
>
> "*The data should (preferably) contain sufficient information of the equipment and sufficient information about the service conditions*."
>
> *"The data should (preferably) easy to retrieve on demand."*
>
> *"In absence of the sufficient data and easily retrievable data management system, the human factor should phase in to compensate the inadequacy. This requires sound engineering judgement and knowledge."*

One important factor in this definition is the emphasis of experienced "people" in the "operating experience feedback loop" as shown in the above flow chart.

7. Conclusion

This paper presents, for the first time, a set of 7 equations describing the EQ process. These equations indirectly imply the role of type test and analysis in achieving the qualification. These equations also identify the position where the operating experience can make contribution to the EQ Program.

Future plan for actively using operating experience in EQ may require the following:

(1) In house data collection and data linkage to external sources.

(2) In house specialist for interpret data and make application to EQ.

Operating experience, which plays a supporting role to type testing and analysis in establishing the EQ Program, will taking the lead role in the preservation of EQ basis since type testing will be the last resort for maintaining qualification in an operating plan and while data from operating experience will be more abundant and more accurate to fit the EQ use. It may need time and effort to begin with, but in the long run it will be proven cost effective.

References:

1. Vincent S. Noonan, “How the NRC is approaching environmental qualification”, NUCLEAR ENGINEERING INTERNATIONAL, February 1985.
2. IEEE Std 323-1974 Revision of IEEE Std 323-1971 (ANSI N41.5-1971) “IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating Stations”
3. IEEE Std 323-1983 “IEEE Standard for Qualifying Class 1E Equipment for Nuclear Power Generating”
4. American Society of Mechanical Engineers, ASME QME-1-1994, “Qualification of Active Mechanical Equipment Used in Nuclear Power plants,”
5. IAEA – TECDOC “Upgrading, Preserving and Reviewing Equipment Qualification in Operational Nuclear Power Plants”, November 1996
6. CSA N290.13 “Requirements for Environmental Qualification of Equipment for CANDU Nuclear Power Plants” (Draft)
7. EPRI: Nuclear Power Plant Equipment Qualification Reference Manual 1992.

Appendix: Case Studies

In the following are some case studies of using operating experience in EQ based on previous event reports.

Case #1: Preservation of Qualified Life: Storage - Shelf Life Management

The most common perception for Qualified Life has been to assume that it begins at plant start-up or when in-service equipment is initially declared operational. In reality, this assumption neglects the degradation has taken place prior to it is placed in service. The period include the component fabrication, shipping and storage at the equipment manufacturing or supplier’s facilities, shipping and storage at the plant site, installation and the period prior to its declared in service. Degradation during these period may be different from that in service condition and therefore may not be addressed in the Environmental Qualification process. Operating Experience will be able to play a complementary role to ensure the Qualified Life is maintained.

Event Report from Operating Experience will be able to:

- Identify the ageing degradation stressors.
- Set requirements for environmental conditions.
- Establish policy, program, and procedure for Shelf Life control.

Example:

Event Report - Neoprene Diaphragms Are Not Stored Adequately To Prevent UV Damage And Hardening (1999)

This event stated that the manufacturer-supplied diaphragms were found to be not packaged properly in stores. They are stored in clear plastic bags exposing these diaphragms to UV damage and hardening.

Neoprene (polychloroprene) is an elastomer produced by the reaction of acetylene and hydrogen chloride to give the monomer. It is widely used in the chemical and petroleum industries because of its outstanding oil and chemical resistance. However, Neoprene is sensitive to UV light and thermal ageing.

In OPG, the issue of shelf life has been recognized. A corporate standard for "Material Management Shelf Life" program was implemented and the station has established "System Surveillance Program for Elastomers". All elastomers rated as EQ should have a shelf life designation, which includes:

- *Elastomers sampled shall be designated as "Shelf Life Items", and for EQ application, they shall be so identified..*
- *"Elastomers shall be protected from exposure to light by placing them in an opaque container, in a drawer or in a covered area.*
- *Elastomers shall not be stored in the vicinity of Sulphuric and Nitric Acid non-vented cabinets and others stored in the vicinity of a chemical storage area.*
- *Elastomers shall be stored in strain free, unstressed state, i.e. they will not be twisted or stacked or folded.*

A suggested "Component/Equipment Life Cycle Time LINE" is listed below:

1. Manufacture component or piece of equipment
2. Test component or piece of equipment
3. Put into storage until delivery to customer
4. Customer receives component or equipment and places into storage
5. Customer installs component or equipment
6. Component or equipment left in unused state
7. Component or equipment commissioned
8. Component or equipment left energized
9. Component or equipment placed into service
10. Component or equipment maintained over expected life cycle
11. Component or equipment exposed to "Stressors" over expected life cycle
12. Component or equipment must operate during and after a DBA
13. Component or equipment decommissioned and removed from service

<u>Notes</u>:

- Any individual time step can range in of minutes to years. Hence, some components such as electrolytic capacitors could be at end of life without ever going into service.
- Time steps 3 through 7 can be repeated numerous times if other vendors are in between the original manufacturer and the end customer.

In this Shelf Life case, the environmental conditions and the ageing stressors are all identified. The qualified life for the equipment/component can easily be established by equations (1) to (7) by analysis (supported by type testing data). The main driving force for maintaining the component qualified life is through the operating feedback loop described in Fig. 4.

Case #2: Preservation of Qualified life: Installation Quality Assurance

Proper installation is a key factor to ensure the qualified life to have a healthy start. For equipment located in the containment, an improperly installed equipment will lead to a situation that it may not be able to fulfill its safety function when required, and in addition, any effort to make remedial modification will not be possible until the next scheduled shutdown.

The most noticeable event on installation quality occurred in 1986. It was reported in a US NRC Information Notice on the "Improper Installation of Heat Shrinkable Tubing."[8]

This information notice described problems involving improper installation of heat shrinkable tubing manufactured by Raychem have been identified at a number of plants.

The general findings are:

1. Improper tube diameters used, as a result, the heat shrinkable tubing was not adhering to the cable jacket.
2. Improper or insufficient overlap onto wire insulation.
3. Use of heat shrinkable tubing directly over fabric cover of wire or over braided cable jackets.
4. Improper bending of tubing/wires inside junction boxes.
5. Insulation damage caused by manipulation before the heat shrinkable tubing had cooled and set completely.

The purpose of applying heat shrinkable tubing over electrical terminations and splices is to provide electrical insulation and thus ensure the functional capability of the control circuit.

If the tubing has not been installed according to the manufacturer's instructions, electrical failures may occur during a range of conditions including off-normal non-accident conditions, mild-environment accident conditions and harsh-environment accident conditions.

The existence of improperly installed heat shrinkable tubing *could* result in multiple equipment inadequacies in safety-related systems. Furthermore, because of the multiple use of heat shrinkable tubing in redundant or triplicate circuits, the impropriety becomes a potential common-mode failure of safety-related systems which could prevent the fulfilment

The Raychem heat shrinkable tubing was tested in certain configurations for equipment qualification for postulated harsh-environment accident conditions. These configurations are included in the manufacturer's installation instructions and identified as "LOCA/HELB accident" or simply "Accident" specifications. For example, the minimum total length of the tubing for a 0.7-1.2 inch connection length is specified as 6 inches minimum for the LOCA/HELB accident case and as 4 inches minimum for the non-accident case. If actual installation configurations are not those specified as having been qualified by type testing, the status of the equipment qualification is indeterminate.

From the safety system's point of view, this case can be described as the feedback to equation (3) – every component in the assembly is qualified but not the assembly itself. The corrective actions resulted from this operating feedback will help to preserve the qualification status.

Case #3: Introducing of New Ageing Stressors

Once the qualification for an equipment or component is established, it is limited to the configuration for which the qualification was carried out. Any introduction of new material or new configuration to the qualified equipment may introduce new failure modes, and therefore

[8] US NRC Information Notice No. 86-53: Improper Installation of Heat Shrinkable Tubing.

must be reviewed and its qualification status re-assessed. This is described in equation (3) in this paper.

There are several WANO reports on the adverse consequences of using adhesive tapes on the surface of qualified equipment.[9] One case is about the use of marking tape on the steam line. The chemical reaction between the tape and the pipe material formed trans-crystalline crack. The tape material has been identified to contain chloride. The chemical reaction became more active by the increase of temperature and the presence of moistures. Such pipe crack, if not noticed, may eventually lead to pipe leak. The second case is the use of “Rad Tape” (denoting radiation boundaries) placed in contact with some stainless steel components of various safety related systems.[10] In this case the manufacturer of the tape was identified. Again the tape was analysed and showed to contain chloride.

The corrective actions for these events are:

1. Preservation of Equipment Qualified Life: Document where tapes were used, removal of the tape carefully and use testing procedures to assure no component damage.
2. Programmatic Action: Set up policy to control the use of consumable materials, such as tapes, on safety related equipment and training of personnel of the consumable material control program.
3. Material Control: Search for tapes that meet the environmental qualification requirements (i.e. not to introduce the inter-component Effect as described in Equation (3) of this paper.)

There are similar but not identical situations which occurred in OPG-N plants. These are the two cases involved the use of colour-coded marking tapes of unknown material on electrical cables. The tape had chemically bonded to the wire insulation, causing embrittlement and cracking of the insulation. Difficulties were encountered in removing the tape which resulted in further damage to the cable insulation. The tape was probably used by Construction electricians during initial installation as a guide to wiring terminations. One other case was the use self-amalgamated electric tape to repair broken cable jacket. In this case the manufacturer of the tape was known but the qualification status was unclear. All three cases constitute a potential trend.

Case #4: Synergistic Effects

Lubricants are used for reducing friction and prevent seizure between surfaces which are in relative sliding motion under pressure. The environmental stressors such are moisture, temperature and radiation degrade the quality of the lubricant. An OPG OPEX event[11] reported in May 1999 found the motor operated valve seized due to hardened grease (appears to be old EP2 grease) and internal limit switch gear teeth with brass shavings in the lubricant. Also, for all similar motor operated valves, valve stems were found dirty and dry and very high packing load is evident when hand wheeling. This condition is typical of lack of maintenance or higher than normal service temperatures.

Similar event of lubricant degradation occurred in a US station[12]. In this case the equipment (valve) failed to operate because the limited amount of lubricant & the qualities of the lubricant used enabled corrosion to take place through the actuator housing.

The corrective action for both event is to replace the existing lubricant with a new type of grease, Mobil 28. This synthetic grease is compatible with the o-rings and has excellent coating and water repellent properties.

[9] EAR PAR 98-010, Chloride Induced Stress Corrosion Cracking Due to Adhesive Tapes on the Surface of the Exhaust Steam Line of the HP Safety Injection System, Philippsburg Unit 1 (Germany) - 97/06/13, WANO Event Analysis Report - Posted 20 May 1998.

[10] WANO ATL 99-021, (INPO OE9719) Improper Use of Tapes and Other Consumable Materials, Three Mile Island U1 (USA) - 98-03-04.

[11] SCR# P-1999-03862 P5 – Heat Transport MOVs Inoperable – 1999/05/29

[12] INPO OE9477 - Lubricant Degradation in Bettis Actuator Caused Functional Failure, 98-08-01.

The synergistic effect by moisture, temperature and radiation degradation can be considered as the operating feedback to equation (5) of this paper.

Case #5: Preservation of Containment Penetration Qualification

The qualification of cable penetration through containment is based on IEEE Standard 317, which described the requirements for type testing.

The containment component leak test data is a typical example of operating experience data that would support the preservation of qualification status throughout the plant life.

The leak test data is a typical feedback to equation (3).

Acknowledgement:

The authors would like to express sincere thanks to Dr. Nigel Nicholson, Mr. Peter Lindsay and Mr. Bill Andersen, all of OPG, for their valuable comments and inputs to this paper. The authors are also grateful to Mr. Neill Allen, Director of EQ Project, and Mr. Neil Mitchell, Manager of EQ Program, both of OPG-N, for their support in preparing this paper.